

**A Cooperative Agreement
Between
Oregon State University
And
U.S. Geological Survey**

1. ADMINISTRATIVE

Project Leaders: Dr. Matthew Betts, Forest Ecosystems and Society, Oregon State University, matthew.betts@oregonstate.edu, Phone: 541-737-3841, Dr. Susan Shirley, Forest Ecosystems and Society, Oregon State University, susan.shirley@oregonstate.edu, Phone: 541-737-6561, Dr. Joan Hagar, USGS-BRD Forest & Rangeland Ecosystem Science Center, joan_hagar@usgs.gov, Phone: 541-737-1487

Project Title: Disentangling the effects of climate and landscape change on bird population trends in the western U.S. and Canada

Agreement #: G11AC20255

Date of Report: April 23, 2014

Reporting period: Aug 2011-Aug 2013

Actual Total Cost: \$ 74,640 + \$ 40,000 leveraged from NSF grant

2. PUBLIC SUMMARY

Changes in climate are often assumed result in changes to species' ranges, with potential impacts on natural system functioning and ecosystem services. 'Climate envelope models', which rely on correlations between climate and species distributions, have been used to predict the future of biodiversity under these assumptions. However, other factors including land-cover, dispersal ability and interspecific competition and facilitation may play an important role in driving species distributions and population trends either alone or in combination with climate. In an ongoing project, we used long-term data on bird distributions and abundance to develop climate envelope and land-use models for 161 species in order to provide a multi-species test of the degree to which climate envelope versus land-use models are useful in predicting species distributions and population trends of birds in forest ecosystems of the western U.S. and Canada. Our results suggest that models describing associations between climatic variables and abundance patterns can be used for some species to predict changes through time, and that changes in climate have already driven shifts in the geographic patterns of abundance of bird populations in western North America. For other species, models using land-use variables including raw remote-sensing variables may provide the best predictions for abundance change. The results of this research showing the reliability of models across multiple species will aid managers in understanding which species are most vulnerable to changes from climate, land-use change and their interaction.

3. TECHNICAL SUMMARY:

We conducted a large, multi-objective study to develop information needed to assess the vulnerability

of western bird species to changes in climate and land-use. We developed climate and land-use models to assess their ability to predict changes in species distributions. The NW CSC funding was critical to our ability to develop the land-use component of this research. This funding allowed us to assess the usefulness of raw remote-sensing data to predict species distributions. Our finding that including raw remote-sensing data as predictor variables produces models with high predictive ability has important implications for the development of species distribution models incorporating land-use change. These models will be particularly effective at incorporating the need for fine-scale resolution land-use change data over large scales. Understanding the relative roles of climate and land-use in affecting species distributions and population trends over time is a critical issue for managing the effects of future environmental change. Our research provides the first direct comparison of the effects of these drivers based on empirical data for a multi-species community. The methodology developed in this research will also provide a template upon which further studies can be conducted across other geographical areas and time periods.

4. PROJECT PURPOSE AND OBJECTIVES

Climate change has been implicated in the range shifts and population declines of many species, but the confounding of climate change with other variables, particularly landscape change, hampers inference about causation. Climate envelope models have been used to predict population trends and future distributions, but the reliability of such predictions remains relatively unknown; without tests of model accuracy, outcomes are too uncertain to support policy development. The objectives of this project are to:

(1) Use 27-year data on bird distributions to test the reliability of climate envelope models

To predict the potential impact of climate change on animal and plant species, most researchers and policy makers use ‘climate envelope’ models that link *current* and *past* species distributions to climate (Peterson et al. 2002); these associations are then projected forward under various climate change scenarios to provide estimates of species vulnerability (Thomas et al. 2004). Changes in climate are implicitly assumed to cause change in species ranges, with potential impacts on natural system functioning and ecosystem services (Botkin et al. 2007; Thomas et al. 2004). For example, observations for some bird species in the Breeding Bird Survey (BBS) show trends in abundance whose spatial patterns suggest northward shifts in range (i.e., positive population growth at the northern range limits), while others show no clear spatial pattern (Figure 1). Though such patterns could be a response to a warming climate, there are a number of other factors that are expected to drive species distributions including interspecific competition and facilitation as well as the distribution of vegetation (Gaston 2009). The reliability of climate envelope models in policy development depends heavily on the degree to which climate, or such alternate factors influence species distributions and population trends. Nevertheless, there have been surprisingly few validations of climate envelope models (Araujo et al. 2005) and to our knowledge, none have been conducted in the Pacific Northwest. Policy decisions would be greatly enhanced by tests of the reliability of such models across multiple species – understanding factors affecting past distributions is critical for making good future predictions. Such an assessment would provide a basis for categorizing species most at risk from climate or land-use change (or their interaction).

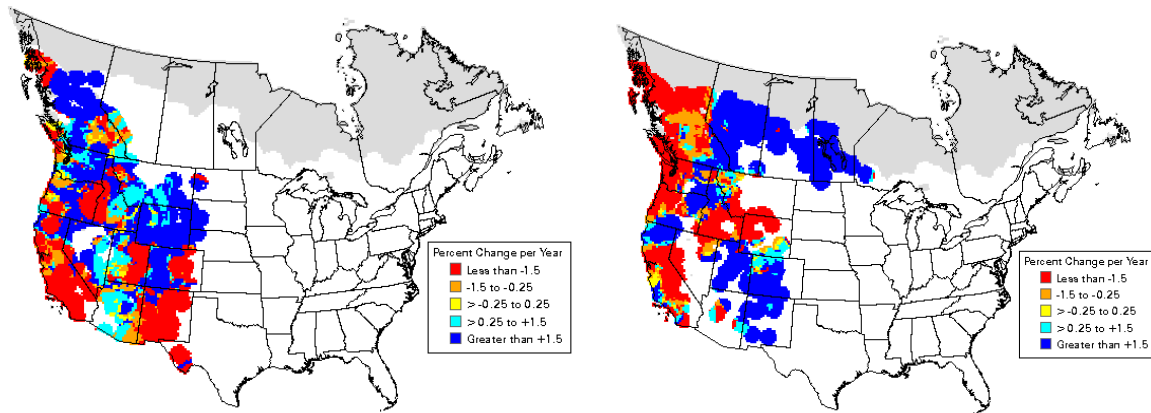


Fig. 1 Geographic distribution of BBS population trends for Violet-green Swallow (A) and Orange-crowned Warbler (B). One of our key objectives is to disentangle the relative influence of climate and landscape change driving such patterns. Note the substantial population declines (delineated in red) in the southern portion of the range of (A) suggesting a connection to warming trends near the southern range limits. In contrast, no clear pattern associated with warming trends is shown in (B) suggesting other factors such as landscape change may be more important. However, without detailed information on landscape change in such regions, this hypothesis has previously been untestable. From <http://www.mbr-pwrc.usgs.gov/bbs/htm03/trn2003/tr06140.gif>

(2) Test whether changes in climate are linked to bird population declines over the past 32 years,

Several of the species we have selected to model are undergoing moderate to large rates of decline (-1 to -4% per year) over the last 30 years (<http://www.rmbo.org/pif/pifdb.html>) in parts of their range. Information on underlying causes of observed declines is urgently needed to avoid further risk to their populations.

(3) Assess the value of using individual raw spectral reflectance bands to explain the influence of land-cover on species distributions

Assessing the influence of land-cover in species distribution modelling is limited by the availability of fine resolution land-cover data appropriate for most species responses. Remote-sensing technology offers great potential for predicting species distributions at large scales. Despite its benefits, there are several limitations to be considered in current uses of remote-sensing data (Turner *et al.*, 2003; Bradley & Fleishman, 2008) for species distribution modelling. The cost and required expertise is prohibitive for many applications. One potential solution to these difficulties is to use raw data on reflectance as explanatory variables in species distribution models. Since the original information for each pixel is retained, such a modelling approach has the potential to improve both the spatial resolution and accuracy of predictions, and avoids the subjectivity associated with the choice of classification method and the loss of information associated with classifying an inherently continuous attribute. Further, because such data are now freely available at high temporal resolution for many areas of the earth's surface (http://landsat.usgs.gov/Landsat_Search_and_Download.php), such an approach would enable researchers in regions where no classified images currently exist to model distributions as a function of land-cover.

(4) Assess the relative importance of climate versus landscape change in explaining changes in species distributions

Land-use is considered to be one of the most important drivers of biodiversity, affecting patterns of species diversity (Jetz *et al.*, 2007; Coops *et al.*, 2009), species distributions (Wilcove *et al.*, 1998; Opdam & Wascher, 2004; Thuiller *et al.*, 2008) and ecological processes (Dickinson, 1991; Dale, 1997; Allan, 2004). However, we have a rather limited understanding of how recent land-use changes have resulted in changes to species distributions over larger scales (regional, continental and global). At broad scales there has been much recent interest in the role of climate as a primary driver of current (Brown, 1995; Chen *et al.*, 2011) and future (Peterson *et al.*, 2002; Thomas *et al.*, 2004) species distributions. While climate may be an important factor, clearly land-use exerts an influence on species distributions; the negative effects of habitat loss on species extinctions are also well known (Balmford *et al.*, 2003). Land-use changes over broad scales have the potential to affect biodiversity through a number of mechanisms such as habitat loss and fragmentation, enabling biological invasions, and impairment of ecological processes critical to ecosystem function. Unfortunately, the relative roles of climate and land-use in affecting species distributions and population trends over relatively short time periods (<50 years) is not well known (Jetz *et al.*, 2007; Lemoine *et al.*, 2007). It has been hypothesized that climate influences distributions at broad scales and long-terms, whereas the influence of land-use is shorter term and at finer spatial scales (Lemoine *et al.*, 2007; Soberon, 2007). However, this hypothesis has been difficult to test because our ability to predict the effects of land-use and land-use change on species distributions has been limited by the availability of estimates of land-use at appropriate spatial and temporal scales. Habitat data at sufficiently fine a resolution to be appropriate to most organisms under study (Mladenoff *et al.*, 1999; Bowman *et al.*, 2001; Mitchell *et al.*, 2001; Betts *et al.*, 2006) are rarely available at scales large enough compare to broad-scale climate data. In addition, species distributions are a function not only of habitat, but also of the spatial arrangement of appropriate habitat conditions in providing conduits and barriers to change (Hill *et al.*, 2006). Thus, appropriate habitat must be considered not only in terms of its abundance, but also its arrangement in both space and time.

(5) Use life-history analyses to determine factors that influence how populations are associated with either habitat loss, climate change, or their combination.

A central challenge in forecasting the impact of drivers such as climate and land-use change on biodiversity is to understand which species are able to adapt to rapidly changing environmental or habitat conditions (Travis 2003; Thuiller 2007). Movement is one possible means for species to respond to climate change. As conditions become inhospitable at some locations within the distributional range, adaptation at the population level may occur through shifting to more appropriate habitat at higher elevations or latitudes. Upward and poleward shifts of species ranges have occurred across a wide range of taxonomic groups and geographical locations during the twentieth century (Parmesan & Yohe 2003). However, there has been great variation across taxa in the degree that range shifting has occurred (Hickling *et al.* 2006). It appears that some species either have less capacity to shift or do not need to shift in order to persist (e.g., Kearney *et al.* 2009). Differential rates of poleward shifting will result in new species assemblages that could influence the behavior of ecosystems as well as the services they provide (Sekercioglu *et al.* 2004). The degree to which generalizations can be made about the sorts of species likely to undertake range shifts have thus been a subject of great recent interest.

Species traits have been hypothesized to underlie the high variability in response to climate change (Kokko & Lopez-Sepulcre 2006; Parmesan 2006). Theoretical studies have shown that these traits should be key predictors of species' response (Travis 2003; Best *et al.* 2007); however, there is little empirical evidence to support this hypothesis (Brommer 2004; Devictor *et al.* 2008) because detailed information on life history and other traits are lacking for species with appropriate long-term distributional data. Species traits are also expected to influence the species responses to land-use change and its interaction with climate change. In some cases, certain traits may allow a species to use a greater variety of habitats or evolve and adapt to novel habitats (Sol *et al.*, 2002; Strayer *et al.*, 2006) while other species with traits that are more narrowly restricted to certain habitats show declines in response to habitat loss. An analysis of important traits would provide an ability to screen for species most at risk from climate or land-use change (or their interaction).

5. ORGANIZATION AND APPROACH

We tested hypotheses about the relative importance of climate and landscape change using novel statistical approaches for modeling species abundance and distributions. We applied a traditional Species Distribution Modeling (SDM) approach using Boosted Regression Trees (BRTs) (Elith et al. 2008). We linked data on climate and forest land-cover to patterns of change in BBS observations and thus provide a quantitative means of comparing the relative roles of climate and landscape change.

(1) Use 27-year data on bird distributions to test the reliability of climate envelope models

A primary objective is to provide a multi-species test of the degree to which climate envelope models are useful in predicting species distributions and population trends of birds in forest ecosystems of the Pacific Northwest. We compiled climate and bird occurrence data for 161 terrestrial bird species for the area covering the western U.S. and the province of British Columbia. To model climate envelopes, we acquired and developed maps from PRISM climate data (Daly et al. 1994) including data on temperature and precipitation at a 1 km²-grain size from 1974 to 2002. We used seven predictor variables that we expected to have influence on species distributions including maximum temperature for June and July (hottest month), minimum temperature for June and January (coldest month), and precipitation for June, July (driest month) and December (wettest month). For bird occurrence data, we used data from The Breeding Bird Survey (BBS), one of the most spatially extensive and long-term wildlife surveys in the world (<http://www.pwrc.usgs.gov/BBS/>). These data have commonly been used to assess bird population trends (Pardieck and Sauer 2000) and in species distribution modeling (Peterjohn 2001). We obtained route maps and associated species abundances for our modeling region (western states and B.C.). To reduce sampling variation in abundance caused by observer and weather effects, we used averages for two five-year windows representing an early (1970-74) and a later period (1998-2002). The BBS routes were overlaid on the climate layers and we intersected buffered areas of 1km around each route with the climate data.

We evaluated both abundance and distribution models in two ways: (1) description of the fit of the original models within a given time period (verification) and (2) model fore-casting and hind-casting with independent data, in our case using models developed during one time period to predict observed patterns in the other period (cross-validation; Araújo & Guisan 2005; Dobrowsky *et al.*, 2011). We verified the models using data from the same time period used for model development. We calculated the performance of the presence/absence models using AUC (area under the receiving operating characteristic curve). Abundance models were evaluated using Spearman's rank correlation coefficients (Spearman's ρ) between predicted (from model-averaged coefficients) against observed abundance values. In contrast to existing approaches, this research explicitly focuses on how well models built from one time period can be applied to test sets from different time periods using methods of fore-casting and hind-casting, and the extent to which errors in the predictions are related to climate covariates. For cross-validation, we used the models developed in one time period and then used the climate data in the other period to predict occurrences or abundance of the selected species in the target routes. These were compared with the observed measures of occurrence and abundance in the test period.

(2) Test whether changes in climate are linked to bird population declines over the past 27 years,

The strongest test of whether the climate variables in (spatial) models are causally linked to species' distributions and abundances is to make predictions about changes over time, and then to test these against observed changes. A given species at a sampling location can (i) colonize, (ii) go locally extinct, (iii) survive, or (iv) remain absent during a given period of time (Nichols *et al.*, 1998; MacKenzie *et al.*, 2003). Thus, we identified the routes where each of these states had been observed (changes in occupancy: absence to presence of n individuals, and *vice versa*). To estimate expected change in occupancy, we ran boosted regression tree (BRT) models using data from the first time period to estimate initial occupancy probability. We then predicted to the second period using this first model given changes in climate that occurred on each route. The difference between these values was considered the expected changes in probability of occupancy. Prediction accuracy was

assessed by comparing expected change with observed change in occupancy status. In the case of the abundance models, we followed a similar procedure; we tested the correlation between expected and observed abundance changes.

(3) Assess the value of using individual raw spectral reflectance bands to explain the influence of land-cover on species distributions

We tested the usefulness of freely available raw remote-sensing reflectance data in predicting species distributions of 40 commonly occurring bird species in the Central Coast Range, Cascade and Klamath Mountains of western Oregon, USA. Information on bird observations was collected from 4,598 fixed-radius point counts. Reflectance data was obtained using 30 m resolution Landsat imagery summarized at scales of 150m, 500m, 1000m and 2000m. Our explanatory variables were the means and standard deviations calculated for Landsat remote-sensing reflectance bands 1, 2, 3, 4, 5 and 7 (hereafter 'Reflectance Models'). In addition, we chose to analyze these predictor variables at 4 scales that have been found to be relevant to passerine bird species: 150 m, 500 m, 1000 m and 2000 m (Betts *et al.*, 2006) for a total of 48 predictor variables. Other species distribution studies commonly use an index derived from bands 3 and 4 known as the Normalized Difference Vegetation Index (NDVI) (Parra *et al.*, 2004; Gottschalk *et al.*, 2005; Gillespie *et al.*, 2008; Morán-Ordóñez *et al.*, 2012). As a further comparison, we developed models for all species using a separate set of covariates that included the NDVI values calculated at each scale (hereafter 'NDVI models'). We used BRT models to analyze relationships between distributions of birds and reflectance values and evaluated prediction performance of the models using area under the receiver operating characteristic curve (AUC) values.

(4) Assess the relative importance of climate versus landscape change in explaining changes in species distributions

This objective assesses the relative importance of changes in climate versus landscape change in determining changes in bird occurrences for a similar time period using the climate and BBS data as well as NDVI change map layers. We assessed whether changes in climate are correlated with changes in bird occurrences over a 27-year period by using BRTs to compare changes in climate and bird occurrence data using five-year averages for the 1983-1987 period with those from 2006-2010. Similar to Objective 1, we used PRISM climate data for data on temperature and precipitation and BBS data for bird abundance and presence/absence. For land-cover data, we generated maps of NDVI (Normalized Difference Vegetation Index) for the time periods 1983-1987 and 2006-2010. We decided to use NDVI layers as our measure of landscape cover because it provided the desired temporal and spatial flexibility of coverages. Because these layers were not immediately available, their preparation caused some delay in our project timing. We also decided to use the individual raw spectral reflectance bands as predictors in our analyses because we have shown these are good predictors of species distributions in other areas (Shirley *et al.* 2013). We intersected buffered areas around each BBS route with forest landscape change and climate data as well as with other data related to landscape position, ecoregion, etc. Data for parts of Oregon and California were made available through Avian Knowledge Northwest, a node of the Avian Knowledge Network (AvianKnowledgeNorthwest.net).

(5) Use life-history analyses to determine factors that influence how populations are associated with either habitat loss, climate change, or their combination.

We applied a general linear modeling approach to evaluate the association of life history attributes with changes to species distributions due to climate change and/or habitat loss. We used five predictor variables that we expected to have an influence on species distributions including longevity, fecundity, foraging method, migration status and habitat type.

(6) PROJECT RESULTS

(1) Use 27-year data on bird distributions to test the reliability of climate envelope models

Models generally showed a good fit for most species within both time periods (internal validation). For presence/absence models, at least 80% of species showed AUC values >0.8 in both time periods. Correlations between observed and predicted abundance were quite high when tested within time periods; Average ρ (\pm se) was 0.47 ± 0.02 for 1970-74 and 0.49 ± 0.01 for 1998-2002 (Fig. 2). Prediction success was lower in validation than in verification, though not substantially. For presence/absence models, 40% of species when forecasting and 59% of species when hindcasting showed excellent (AUC > 0.8) predictive performance between time periods. For abundance models, 61% and 72% of species (for forecasting and backcasting, respectively) showed correlations $\rho > 0.3$.

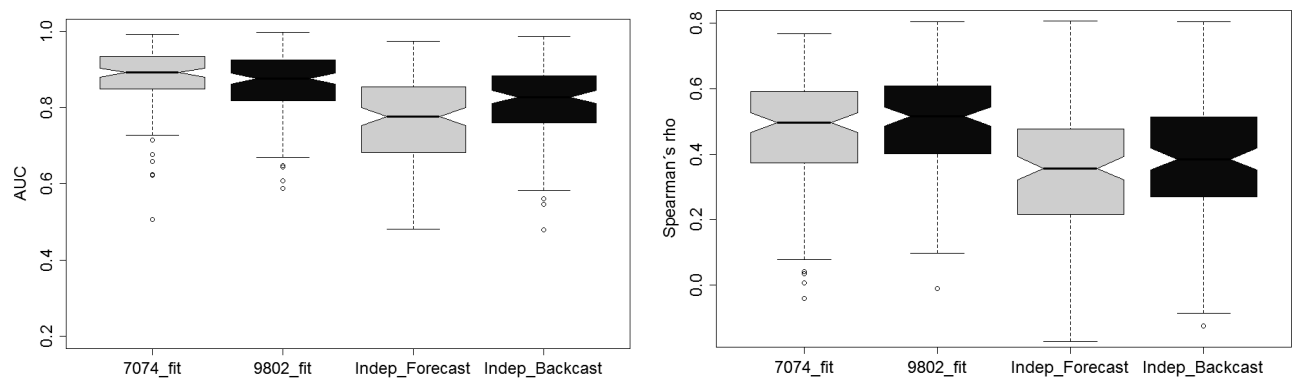


Fig 2. Summary of model performance evaluation for a) distribution (presence/absence) and b) abundance models. Presence/absence models were evaluated via AUC and abundance models were evaluated using Spearman's rank correlation coefficients between observed and predicted abundance at each route. 7074_fit = AUC and r for the model tested within a single time period. Indep_Forecast/ Backcast are for forecast and backcast predictions respectively.

(2) Test whether changes in climate are linked to bird population declines over the past 27 years,

We tested the capacity of models to predict occupancy changes through time for 98 species that satisfied criteria for analyses. In general, models tended to predict the local extinctions better than the local colonisations. We found 70 of the 98 species showing a decrease in average climate suitability over time in the routes where these species went locally extinct. In the case of colonized routes we found 52 species that showed increase in average predicted suitability. In predicting changes in abundance over time, 71 out of 132 species showed significant correlations between observed and predicted change. Model quality varied widely with 61 species showing weak predictive power ($\rho < 0.2$), 24 species showing some level of predictive power ($0.2 > \rho < 0.5$) and 47 species showing correlations >0.5 . Similar to the results of the occupancy models, there is some indication that climate-related declines are predicted better than increases in local abundances.

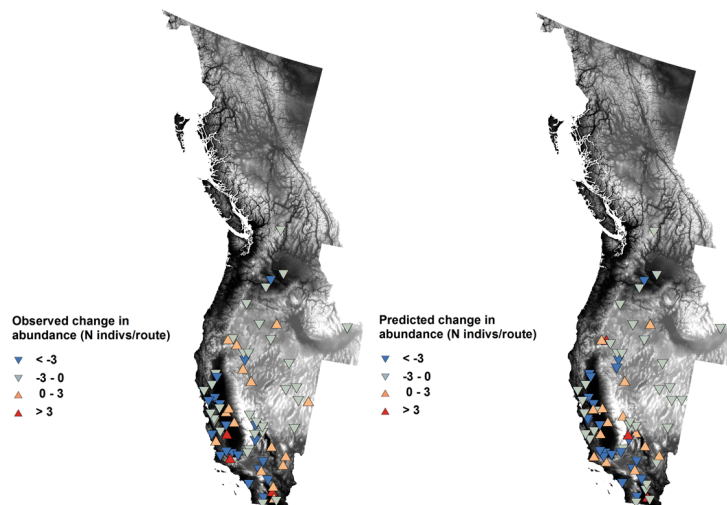


Fig 3. Observed and predicted predicted abundance changes for Loggerhead shrike (*Lanius ludovicianus*), a species with a typical northern distribution in North America. Blue down arrows show the routes were the species is declining and red up arrows show the routes were the species has increased in numbers.

(3) Assess the value of using individual raw spectral reflectance bands to explain the influence of land-cover on species distributions

Prediction success of models using all reflectance values was high (mean AUC = 0.79 ± 0.10 SD). Further, model performance using individual reflectance bands exceeded those that used only Normalized Difference Vegetation Index (NDVI). The relative influence of band 4 predictors was highest, indicating the importance of variables associated with vegetation biomass and photosynthetic activity. Across spatial scales, the average influence of predictors at the 2000 m scale was greatest (Fig. 4).

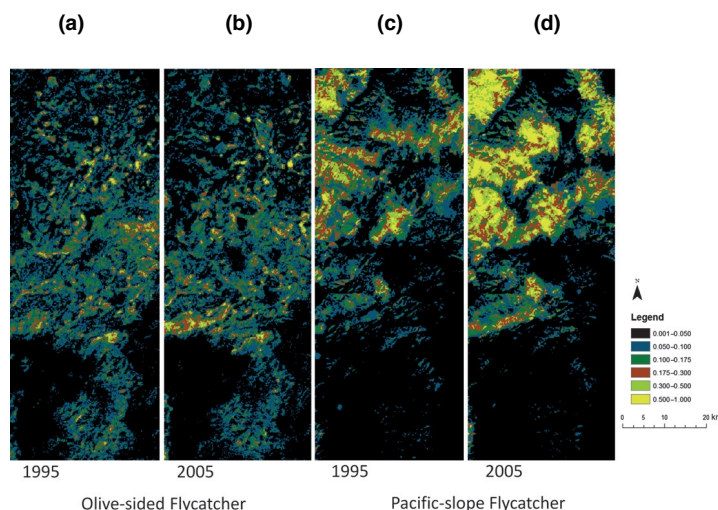


Fig 4. Predicted potential spatial distribution in western Oregon of the Olive-sided Flycatcher (*Contopus cooperi*) ((a) and (b)) and Pacific-slope Flycatcher (*Empidonax difficilis*) ((c) and (d)) in 1995 and 2005 estimated from boosted regression tree models using Landsat TM spectral reflectance bands as predictor variables. Colors refer to probability of occurrence where yellow indicates the highest probability and black the lowest probability.

(4) Assess the relative importance of climate versus landscape change in explaining changes in species distributions

Models with climate variables included as predictors gave the highest predictive success, based on AUC values, when using 1983-1987 data to forecast species distributions for the later period (2006-2010) (Figure 5). Models with climate variables do very well and there is not a substantial gain from adding information from NDVI and

raw band data. Models using only NDVI had the lowest predictive success with the raw band models doing slightly better. These models can be used to produce maps of species distributions (Figure 6).

Fig. 5. Mean species distribution model results showing AUC values for models forecasted to 2006-2010 using model data from 1983-1987. Groups of models have climate, NDVI and raw reflectance bands as variables both singly and in combinations.

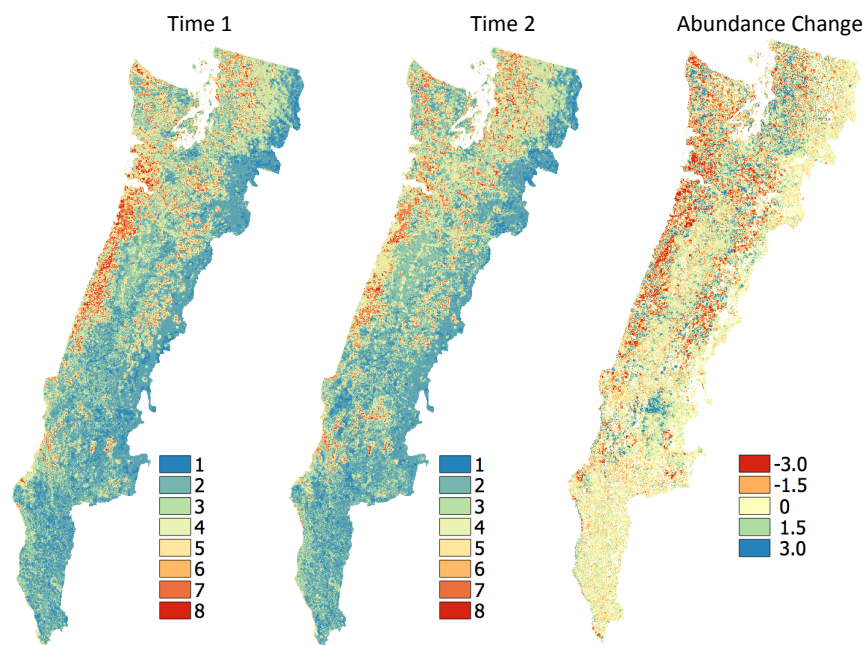
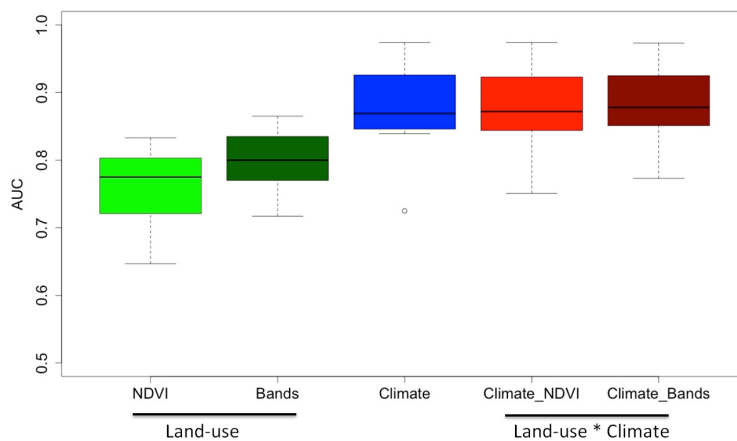


Fig. 6a. Predicted distributions of rufous hummingbird using climate and land-use variables for 1983-1987 (Time 1) and 1998-2002 (Time 2) as predictors in a section of western Oregon. Numbers show raw abundances for the two time periods and the predicted abundance change. Correlation between observed and predicted abundance was $r=0.49$.

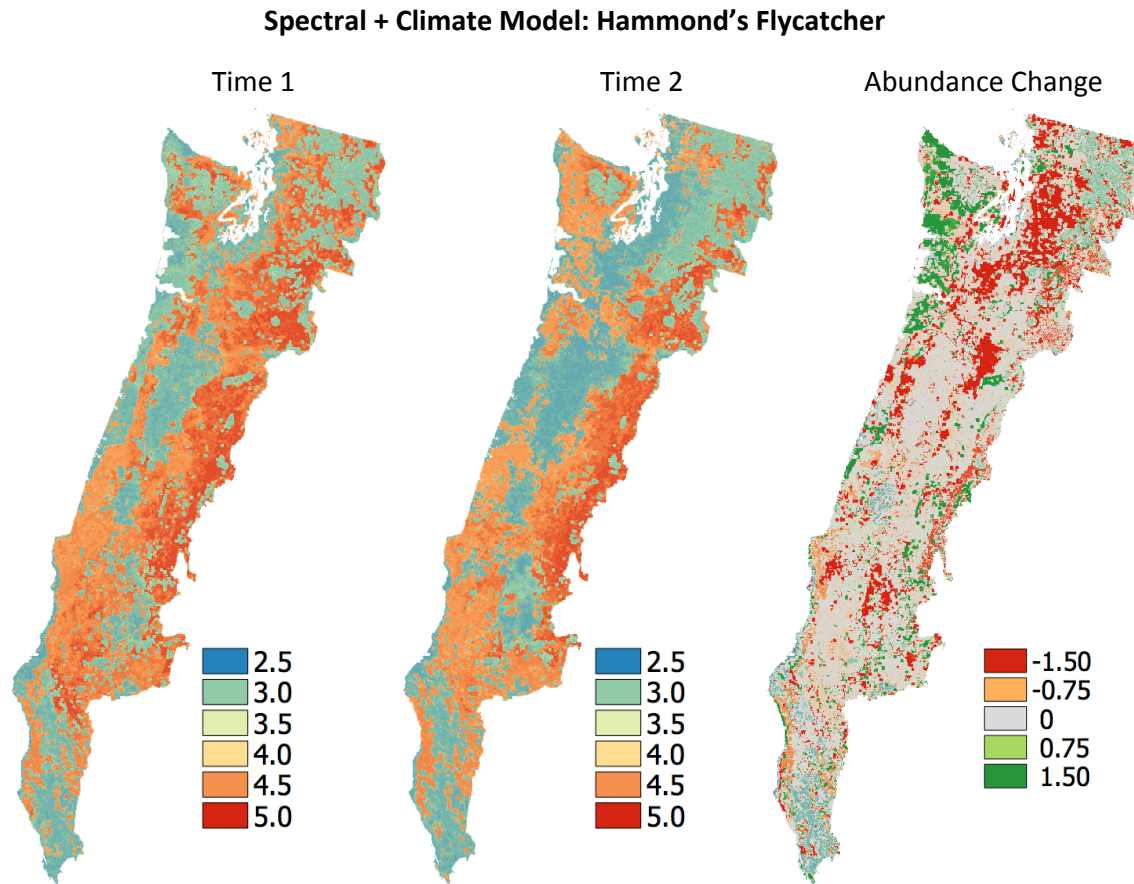


Fig. 6b. Predicted distributions of Hammond's flycatcher using climate and land-use variables for 1983-1987 (Time 1) and 1998-2002 (Time 2) as predictors in a section of western Oregon. Numbers show raw abundances for the two time periods and the predicted abundance change. Correlation between observed and predicted abundance was $r=0.66$.

We compared the correlations of predicted and observed population trends between models with land-use, climate and both sets of variables. Both climate and land-use appear to have relatively weak, but detectable association with population trends (Figure 7). The associations are most prevalent for species with models developed from climate variables (blue dots); 25% of species had significant associations while models developed with land-use (green dots) variables were significant for 17% of species.

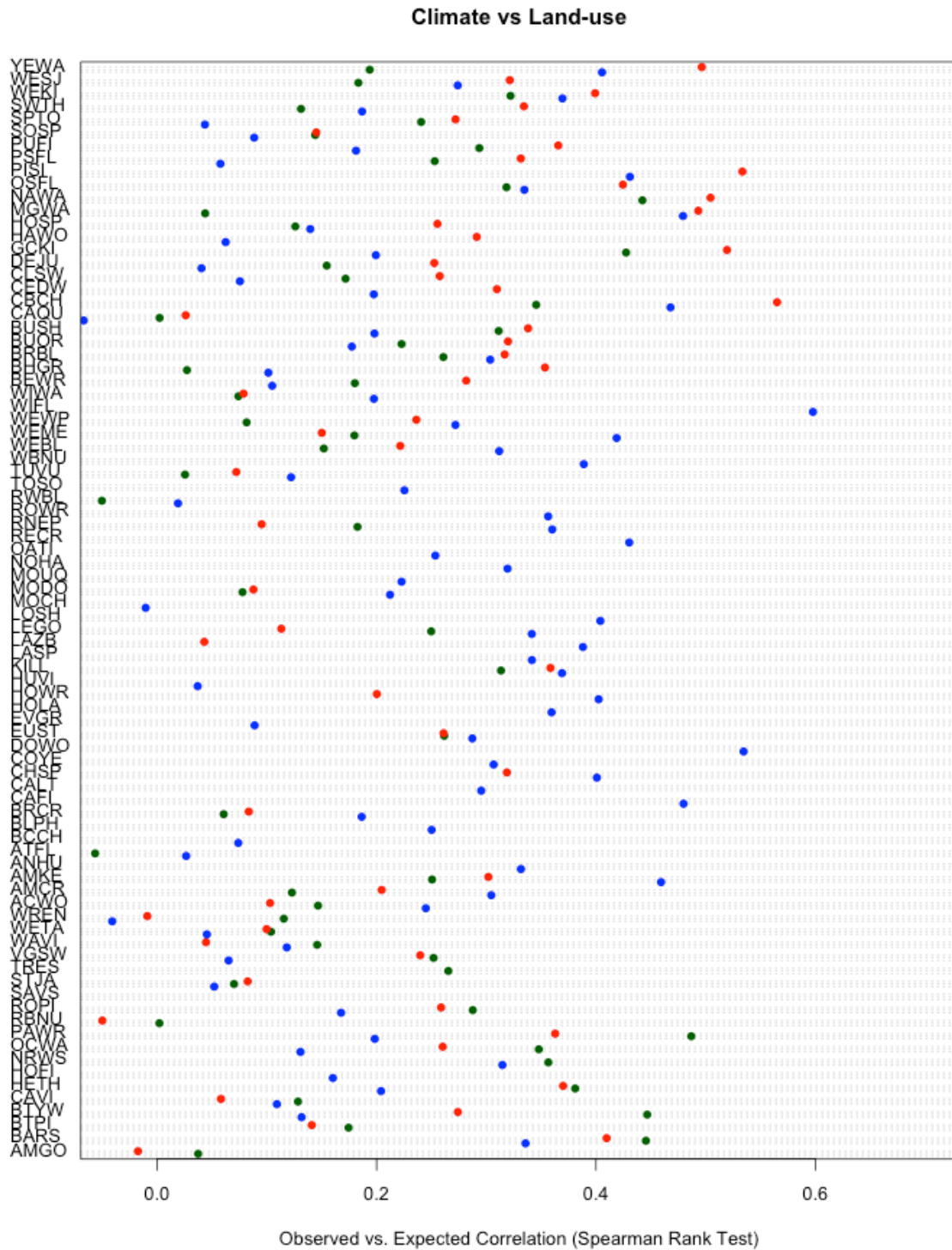


Fig. 7. Correlations of predicted population trends for 1983-2010 versus observed population trends developed from climate, land-use and climate + land-use species distribution models. Trends for species with text highlighted in blue are best predicted by climate models while those highlighted in green are better predicted by models with a land-use variable component.

(5) Use life-history analyses to determine factors that influence how populations are associated with either habitat loss, climate change, or their combination.

Our preliminary analysis indicates that some species traits (migratory status, fecundity and habitat) appear to be significantly associated with climate model performance. This objective will require further analysis for climate and land-use models.

7. ANALYSIS AND FINDINGS

Our research has several findings that contribute to the ability to predict bird responses to changes in climate and land-use over time. We developed new approaches that can be used to model species distributions using fine-scale resolution data over regional large scales. Our climate models using boosted regression trees gave high predictive success for species occupancy. This research is among the first to also attempt to predict changes in species abundances. While the models for abundance changes performed less well than occupancy models, they performed reasonably well for most species. Our investigation on the role of land-use in predicting species distributions yielded some important discoveries. We described a novel approach for modeling the influence of land-use using raw remote-sensing data that yield models with high predictive success. A major part of the overall project was the advances in methodology for assembling data for analysis. The availability of fine-scale land-use data has been a major constraint for these types of models and has limited the ability of researchers to compare the influence of land-use and climate changes over large scales. We discovered solutions for assembling and combining BBS bird data, climate data and land-use data that can be used for future research questions.

8. CONCLUSIONS AND RECOMMENDATIONS

Funding from the Northwest Climate Science Centre was used to develop models to investigate the influence of land-use on changes in bird distributions for 161 species. This research was supported by additional NSF funding to develop models addressing the influence of climate variables. We verified the reliability of climate models to predict bird distributions and these models were able to predict changes in abundance over time for a majority of species. We also confirmed that raw remote-sensing variables provide good models for predicting bird species distributions. Comparing climate and land-use models, we found that for most species climate models are superior for predicting changes in species distributions.

The most significant problem we encountered in our research was the lack of availability of land-cover data over the required spatial scale and time periods for comparisons with the climate data. We decided to use NDVI layers as our measure of landscape cover because it provided the desired temporal and spatial flexibility; however, these layers were not immediately available and their preparation caused some delay in our project timing. In addition, although the original proposal focused on 30 forest-dwelling bird species, we expanded the number of species to include 161 terrestrial bird species and their analyses required a longer time-frame than originally expected.

We were not able to complete our life history analysis due to the additional time required to build our models. Our next steps will be completing the life history analyses and finishing the writing of publications for objectives 1, 2 and 4. The manuscript on the response of birds to climate change will be submitted in the near future. The writing for the manuscript concerning the comparison of climate and land-use effects on changes in bird distributions is currently underway.

Although climate envelope models perform well for a number of species, many species are predicted poorly by climate. For species that are poorly predicted by climate, one direction for further study is to examine whether landscape fragmentation is a primary factor influencing declines. We could test two primary hypotheses for these

poor predictions: (1) climate effects interact with habitat loss and fragmentation to drive species distributions and population trends. This mechanism could occur if species' dispersal to new areas within their climate niche is prevented by habitat fragmentation (Opdam and Wascher 2004). (2) complex topography buffers species against potential negative impacts of climate change (Dobrowski 2011). If in warm or dry years, species in mountainous landscapes are able to retreat to nearby areas that are cooler or wetter, this should result in more stable populations and lower likelihood of local extinction over the long term. For species that are well predicted by climate, we could apply our models to future climate variables to forecast those species at risk of decline due to changes in climate. **An alternative hypothesis for poor model prediction is that observers may be less likely to recognize new species as they shift their ranges and subsequently colonize BBS sampling areas (e.g., Zuckerburg et al. 2011). In future years, this possibility may be testable given that routes are now sampled in such a way – via spatial replication – to account for imperfect detection.**

9. MANAGEMENT APPLICATIONS AND PROJECTS

Joan Hagar at the USGS was a collaborator on the land-use section of this project. John Alexander of the Klamath Bird Observatory was a collaborator on the remote-sensing section and contributed data for analysis. The results from this research will provide information on how changes in climate and land-cover influence species distributions of many landbirds in the western United States. Managers will be able to apply these insights to focus conservation efforts on species showing the greatest declines.

10. OUTREACH

Articles in preparation, under review, accepted, or published in peer reviewed journals and other non-peer reviewed journals:

(1) Shirley, S.M., Yang, Z., Hutchinson, R.H., Alexander, J.D., McGarigal, K., and M.G. Betts. 2013. Species distribution modelling for the people: unclassified landsat TM imagery predicts bird occurrence at fine resolutions. *Diversity and Distributions*. DOI: 10.1111/ddi.12093, pp. 1-12

(2) Illan, J.G., Thomas C.D., Jones J.A., Anderson B.J., Shirley S.M. and Betts M.G. *in prep*. Modelling bird populations in the Pacific Northwest: implications for species responses to recent climate change

(3) Betts M.G., Shirley S.M., Ziquiang Y. and Illan J.G. *in prep*. Climate change and land-use impacts on bird population trends in the mountainous regions of Western North America

Conference presentations, seminars, webinars, workshops, or other presentations to the public made by research team members:

Betts M.G., Shirley S.M. and Hadley, S. 2012. On the influence of land-use and climate change on animal (*mainly bird*) distributions. Webinar for OSU Climate Change Teacher Institute, Corvallis, Oregon, Feb 2012.

Illan, J.G., Thomas C.D., Betts M.G. On the influence of climate change on bird distributions: Will the predictions come true? Department of Biology Workshop. The University of York. York, United Kingdom Feb 2012.

Shirley, S.M., Yang, Z., Hutchinson, R.A., Alexander, J.D., McGarigal, K. and Betts, M.G. 2012. Unclassified landsat TM predicts bird distributions at fine resolutions in forested landscapes. The Ecological Society of America Conference, Portland, Oregon, Aug. 2012.

Illan, J.G., Thomas C.D., Jones J.A., Anderson B.J., Shirley S.M. and Betts M.G., 2012. Modelling bird populations in the Pacific Northwest: Implications for species responses to recent climate change. The Ecological Society of America (ESA) Conference, Portland Oregon, Aug. 2012.

Betts M.G., Illan J.G., Shirley S.M., and Ziquiang Y. 2012. Climate change and land-use impacts on bird population trends in the mountainous regions of Western North America. The Wildlife Society Conference, Portland, Oregon, Nov 2012.

Matt Betts, invited talk, Texas Tech University, Lubbock, November 2012

REFERENCES

- Allan, J.D. (2004) Landscapes and riverscapes: The influence of land use on stream ecosystems. *Annual Review of Ecology and Systematics*, **35**, 257-284.
- Araujo, M. B., R. G. Pearson, W. Thuiller, and M. Erhard. 2005. Validation of species-climate impact models under climate change. *Global Change Biology* **11**:1504-1513.
- Balmford, A., Green, R.E., & Jenkins, M. (2003) Measuring the changing state of nature. *Trends in Ecology & Evolution*, **18**, 326-330.
- Best A.S., Johst K., Munkemuller T. & Travis J.M.J. (2007). Which species will successfully track climate change? The influence of intraspecific competition and density dependent dispersal on range shifting dynamics. *Oikos*, **116**, 1531-1539.
- Betts, M.G., Diamond, A.W., Forbes, G.J., Villard, M.A., & Gunn, J.S. (2006) The importance of spatial autocorrelation, extent and resolution in predicting forest bird occurrence
- Betts, M. G., Hagar, J.C., Rivers, J.W., Alexander, J.D., McGarigal, K. & McComb, B.C. (2010). Thresholds in forest bird occurrence as a function of the amount of early-seral broadleaf forest at landscape scales. *Ecological Applications*, **20**, 2116-2130.
- Botkin, D.B., Saxe, H., Araujo, M.B., & al., e. (2007). Forecasting the effects of global warming on biodiversity. *BioScience*, **57**, 227-236
- Bowman, J., Forbes, G., & Dilworth, T. (2001) Landscape context and small-mammal abundance in a managed forest. *Forest Ecology and Management*, **140**, 249-255.
- Bradley, B.A. & Fleishman, E. (2008) Can remote sensing of land cover improve species distribution modelling? *Journal of Biogeography*, **35**, 1158-1159.
- Brommer J.E. (2004). The range margins of northern birds shift polewards. *Annales Zoologici Fennici*, **41**, 391-397.
- Brown, J.H. (1995) Species, niches, and communities. *Macroecology* (ed. by J. H. Brown), pp 26-46. The University of Chicago Press, Chicago, USA.
- Chen, I.C., Hill, J.K., Ohlemuller, R., Roy, D.B., & Thomas, C.D. (2011) Rapid range shifts of species associated with high levels of climate warming. *Science*, **333**, 1024-1026.

- Cohen, W. B., Spies, T. A., Alig, R. J., Oetter, D.R., Maier-Sperger, T.K. & Fiorella, M. (2002). Characterizing 23 years (1972-1995) of stand replacement disturbance in western Oregon forests with Landsat imagery. *Ecosystems*, **5**, 122-137
- Coops, N.C., Wulder, M.A., & Iwanicka, D. (2009) Exploring the relative importance of satellite-derived descriptors of production, topography and land cover for predicting breeding bird species richness over Ontario, Canada. *Remote Sensing of Environment*, **113**, 668-679.
- Dale, V.H. (1997) The relationship between land-use change and climate change. *Ecological Applications*, **7**, 753-769.
- Daly, C., Neilson, R.P., & Phillips, D.L. (1994). A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology*, **33**, 140-158
- Devictor V., Julliard R., Couvet D. & Jiguet F. (2008). Birds are tracking climate warming, but not fast enough. *Proceedings of the Royal Society B-Biological Sciences*, **275**, 2743-2748
- Dickinson, R.E. (1991) Global change and terrestrial hydrology - a review. *Tellus* **43**, 176-181
- Dobrowski, S.Z. (2011). A climatic basis for microrefugia: the influence of terrain on climate. *Global Change Biology*, **17**, 1022-1035.
- Elith, J., Leathwick, J.R. & Hastie, T. (2008). A working guide to boosted regression trees. *Journal of Animal Ecology*, **77**, 802-813
- Gaston, K.J. (2009). Geographic range limits: achieving synthesis. *Proceedings of the Royal Society B*, **276**, 1395-1406
- Gillespie, T.W., Foody, G.M., Rocchini, D., Giorgi, A.P., & Saatchi, S. (2008) Measuring and modelling biodiversity from space. *Progress in Physical Geography*, **32**, 203-221.
- Gottschalk, T.K., Huettmann, F., & Ehlers, M. (2005) Thirty years of analysing and modelling avian habitat relationships using satellite imagery data: a review. *International Journal of Remote Sensing*, **26**, 2631-2656.
- Hickling R., Roy D.B., Hill J.K., Fox R. & Thomas C.D. (2006). The distributions of a wide range of taxonomic groups are expanding polewards. *Global Change Biology*, **12**, 450-455.
- Hill, J.K., Hughes, C.L., Dytham, C., & Searle, J.B. (2006) Genetic diversity in butterflies: interactive effects of habitat fragmentation and climate-driven range expansion. *Biology Letters*, **2**, 152-154.
- Jetz, W., Wilcove, D.S., & Dobson, A.P. (2007) Projected impacts of climate and land-use change on the global diversity of birds. *Plos Biology*, **5**, 1211-1219.
- Kearney M., Shine R. & Porter W.P. (2009). The potential for behavioral thermoregulation to buffer "cold-blooded" animals against climate warming. *Proceedings of the National Academy of Sciences of the United States of America*, **106**, 3835-3840.
- Kokko H. & Lopez-Sepulcre A. (2006). From individual dispersal to species ranges: Perspectives for a changing world. *Science*, **313**, 789-791.
- Lemoine, N., Bauer, H.G., Peintinger, M., & Bohning-Gaese, K. (2007) Effects of climate and land-use change on

- species abundance in a central European bird community. *Conservation Biology*, **21**, 495-503.
- Mitchell, M.S., Lancia, R.A., & Gerwin, J.A. (2001) Using landscape-level data to predict the distribution of birds on a managed forest: Effects of scale. *Ecological Applications*, **11**, 1692-1708.
- Mladenoff, D.J., Sickley, T.A., & Wydeven, A.P. (1999) Predicting gray wolf landscape recolonization: Logistic regression models vs. new field data. *Ecological Applications*, **9**, 37-44.
- Moran-Ordóñez, A., Suárez-Seoane, S., Elith, J., Calvo, L., & de Luis, E. (2012) Satellite surface reflectance improves habitat distribution mapping: a case study on heath and shrub formation in the Cantabrian Mountains (NW Spain). *Diversity and Distributions*, **18**, 588-602.
- Ohmann, J.L. & Gregory, M.J. (2002). Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, U.S.A. *Canadian Journal of Forest Research*, **32**, 725-741.
- Opdam, P. & Wascher, D. (2004). Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. *Biological Conservation*, **117**, 285-297
- Pardieck, K.L. & Sauer, J.R. (2000). The 1996-1999 summary of the North American breeding bird survey. *Bird Populations*, **5**, 30-48
- Parmesan C. & Yohe G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, **421**, 37-42.
- Parmesan C. (2006). Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology Evolution and Systematics*, **37**, 637-669
- Parra, J.L., Graham, C.C., & Freile, J.F. (2004) Evaluating alternative data sets for ecological niche models of birds in the Andes. *Ecography*, **27**, 350-360.
- Peterjohn, B. G. (2001). Some considerations on the use of ecological models to predict species' geographic distributions. *The Condor*, **103**, 661-663
- Peterson, A. T., M. A. Ortega-Huerta, J. Bartley, V. Sanchez-Cordero, J. Soberon, R. H. Buddemeier, and D. R. B. Stockwell. 2002. Future projections for Mexican faunas under global climate change scenarios. *Nature* **416**:626-629.
- Sekercioglu C.H., Daily G.C. & Ehrlich P.R. (2004). Ecosystem consequences of bird declines. *Proceedings of the National Academy of Sciences of the United States of America*, **101**, 18042-18047.
- Shirley, S.M., Yang, Z., Hutchinson, R.H., Alexander, J.D., McGarigal, K., and M.G. Betts. (2013). Species distribution modelling for the people: unclassified landsat TM imagery predicts bird occurrence at fine resolutions. *Diversity and Distributions*. DOI: 10.1111/ddi.12093, pp. 1-12
- Soberon, J. (2007) Grinnellian and Eltonian niches and geographic distributions of species. *Ecology Letters*, **10**, 1115-1123
- Sol, D., Timmermans, S. & Lefebvre, L. (2002) Behavioural flexibility and invasion success in birds. *Animal Behaviour*, **63**, 495-502.

- Strayer, D. L., Eviner, V. T., Jeschke, J. M. & Pace, M. L. (2006) Understanding the long-term effects of species invasions. *Trends in Ecology and Evolution*, 21, 645-651
- Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, O. L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. *Nature* 427:145-148.
- Thuiller, W., Albert, C., Araujo, M.B., Berry, P.M., Cabeza, M., Guisan, A., Hickler, T., Midgely, G.F., Paterson, J., Schurr, F.M., Sykes, M.T., & Zimmermann, N.E. (2008) Predicting global change impacts on plant species' distributions: Future challenges. *Perspectives in Plant Ecology Evolution and Systematics*, 9, 137-152.
- Thuiller W. (2007). Biodiversity - Climate change and the ecologist. *Nature*, 448, 550-552.
- Travis J.M.J. (2003). Climate change and habitat destruction: a deadly anthropogenic cocktail. *Proceedings of the Royal Society of London Series B-Biological Sciences*, 270, 467-473
- Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., & Steininger, M. (2003) Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution*, 18, 306-314.
- Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A., & Losos, E. (1998) Quantifying threats to imperiled species in the United States. *Bioscience*, 48, 607-615.
- Zuckerburg et al. 2011. Climatic constraints on wintering bird distributions are modified by urbanization and weather, *Journal of Animal Ecology* 80: 403–413

Appendix 1 – List of bird species used in the species distribution models for the western U.S.

BBS Species Numbers	Common Name	AOU CODE
1900	American Bittern	AMBI
2730	Killdeer	KILL
2780	Snowy Plover	SNPL
2870	Black Oystercatcher	BLOY
2882	Chukar	CHUK
2920	Mountain Quail	MOUQ
2940	California Quail	CAQU
2970	Dusky Grouse	DUGR
3000	Ruffed Grouse	RUGR
3091	Ring-necked Pheasant	RNEP
3100	Wild Turkey	WITU
3120	Band-tailed Pigeon	BTPI
3131	Rock Pigeon	ROPI
3160	Mourning Dove	MODO
3250	Turkey Vulture	TUVU
3280	White-tailed Kite	WTKI
3310	Northern Harrier	NOHA
3320	Sharp-shinned Hawk	SSHA
3330	Cooper's Hawk	COHA
3340	Northern Goshawk	NOGO
3390	Red-shouldered Hawk	RSHA

3420	Swainson's Hawk	SWHA
3490	Golden Eagle	GOEA
3520	Bald Eagle	BAEA
3550	Prairie Falcon	PRFA
3600	American Kestrel	AMKE
3850	Greater Roadrunner	GRRO
3930	Hairy Woodpecker	HAWO
3940	Downy Woodpecker	DOWO
3970	Nuttall's Woodpecker	NUWO
3990	White-headed Woodpecker	WHWO
4000	Black-backed Woodpecker	BBWO
4021	Red-naped Sapsucker	RNSA
4030	Red-breasted Sapsucker	RBSA
4040	Williamson's Sapsucker	WISA
4050	Pileated Woodpecker	PIWO
4070	Acorn Woodpecker	ACWO
4080	Lewis's Woodpecker	LEWO
4220	Black Swift	BLSW
4240	Vaux's Swift	VASW
4250	White-throated Swift	WTSW
4290	Black-chinned Hummingbird	BCHU
4310	Anna's Hummingbird	ANHU
4330	Rufous Hummingbird	RUHU
4360	Calliope Hummingbird	CAHU
4440	Eastern Kingbird	EAKI
4470	Western Kingbird	WEKI
4540	Ash-throated Flycatcher	ATFL
4570	Say's Phoebe	SAPH
4580	Black Phoebe	BLPH
4590	Olive-sided Flycatcher	OSFL
4620	Western Wood-Pewee	WEWP
4641	Pacific-slope Flycatcher	PSFL
4660	Willow Flycatcher	WIFL
4670	Least Flycatcher	LEFL
4680	Hammond's Flycatcher	HAFL
4690	Dusky Flycatcher	DUFL
4691	Gray Flycatcher	GRFL
4740	Horned Lark	HOLA
4750	Black-billed Magpie	BBMA
4780	Steller's Jay	STJA
4810	Western Scrub-Jay	WESJ
4840	Gray Jay	GRAJ
4880	American Crow	AMCR
4910	Clark's Nutcracker	CLNU
4930	European Starling	EUST
4950	Brown-headed Cowbird	BHCO
4970	Yellow-headed Blackbird	YHBL
4980	Red-winged Blackbird	RWBL
5011	Western Meadowlark	WEME
5080	Bullock's Oriole	BUOR
5100	Brewer's Blackbird	BRBL
5140	Evening Grosbeak	EVGR
5170	Purple Finch	PUFI

5180	Cassin's Finch	CAFI
5190	House Finch	HOFI
5210	Red Crossbill	RECR
5290	American Goldfinch	AMGO
5300	Lesser Goldfinch	LEGO
5310	Lawrence's Goldfinch	LAGO
5330	Pine Siskin	PISI
5400	Vesper Sparrow	VESP
5420	Savannah Sparrow	SAVS
5460	Grasshopper Sparrow	GRSP
5480	Le Conte's Sparrow	LCSP
5520	Lark Sparrow	LASP
5540	White-crowned Sparrow	WCSP
5600	Chipping Sparrow	CHSP
5620	Brewer's Sparrow	BRSP
5671	Dark-eyed Junco	DEJU
5730	Black-throated Sparrow	BTSP
5740	Sage Sparrow	SAGS
5810	Song Sparrow	SOSP
5830	Lincoln's Sparrow	LISP
5850	Fox Sparrow	FOSP
5880	Spotted Towhee	SPTO
5900	Green-tailed Towhee	GTTO
5911	California Towhee	CALT
5960	Black-headed Grosbeak	BHGR
5990	Lazuli Bunting	LAZB
6070	Western Tanager	WETA
6120	Cliff Swallow	CLSW
6130	Barn Swallow	BARS
6140	Tree Swallow	TRES
6150	Violet-green Swallow	VGSW
6160	Bank Swallow	BANS
6170	Northern Rough-winged Swallow	NRWS
6190	Cedar Waxwing	CEDW
6200	Phainopepla	PHAI
6220	Loggerhead Shrike	LOSH
6240	Red-eyed Vireo	REVI
6270	Warbling Vireo	WAVI
6290	Blue-headed Vireo	BHVI
6291	Cassin's Vireo	CAVI
6320	Hutton's Vireo	HUVI
6450	Nashville Warbler	NAWA
6460	Orange-crowned Warbler	OCWA
6520	Yellow Warbler	YEWA
6556	Yellow-rumped Warbler	YRWA
6650	Black-throated Gray Warbler	BTYW
6680	Townsend's Warbler	TOWA
6690	Hermit Warbler	HEWA
6750	Northern Waterthrush	NOWA
6800	MacGillivray's Warbler	MGWA
6810	Common Yellowthroat	COYE
6830	Yellow-breasted Chat	YBCH
6850	Wilson's Warbler	WIWA

6860	Canada Warbler	CAWA
6870	American Redstart	AMRE
6882	House Sparrow	HOSP
7010	American Dipper	AMDI
7020	Sage Thrasher	SATH
7030	Northern Mockingbird	NOMO
7040	Gray Catbird	GRCA
7100	California Thrasher	CATH
7150	Rock Wren	ROWR
7170	Canyon Wren	CANW
7190	Bewick's Wren	BEWR
7210	House Wren	HOWR
7221	Pacific Wren	PAWR
7250	Marsh Wren	MAWR
7260	Brown Creeper	BRCR
7270	White-breasted Nuthatch	WBNU
7280	Red-breasted Nuthatch	RBNU
7300	Pygmy Nuthatch	PYNU
7330	Oak Titmouse	OATI
7350	Black-capped Chickadee	BCCH
7380	Mountain Chickadee	MOCH
7410	Chestnut-backed Chickadee	CBCH
7420	Wrentit	WREN
7430	Bushtit	BUSH
7480	Golden-crowned Kinglet	GCKI
7490	Ruby-crowned Kinglet	RCKI
7510	Blue-gray Gnatcatcher	BGGN
7540	Townsend's Solitaire	TOSO
7560	Veery	VEER
7580	Swainson's Thrush	SWTH
7590	Hermit Thrush	HETH
7630	Varied Thrush	VATH
7670	Western Bluebird	WEBL
7680	Mountain Bluebird	MOBL